OVERVIEW OF THE ACTIVITIES IN THE FIELD OF SEISMIC SAFETY ANALYSIS, TESTS AND RESEARCHES AT JNES

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Abstract

Japan Nuclear Energy Safety Organization (JNES), an incorporated administrative agency was established on October 1, 2003. JNES is a professional organization with the role to ensure safety in the use of nuclear energy in corporation with the regulatory authority, the Nuclear and Industrial Safety Agency (NISA). The field of seismic safety analysis, seismic tests and researches is one of the important missions of the JNES. The activities in the seismic field at JNES, with the points on the analysis and evaluation of seismic input motion and recent topics, will be overviewed.
Introduction

Japan Nuclear Energy Safety Organization (JNES), an incorporated administrative agency was established on October 1, 2003. JNES is a professional organization with the missions to ensure safety in the use of nuclear energy in cooperation with the regulatory authority, the Nuclear and Industrial Safety Agency (NISA). The activities at JNES include inspection of nuclear installations and facilities; safety analysis and evaluation; emergency preparedness support; tests and research for ensuring nuclear safety; and information collection, analysis and transmission to assure nuclear safety. Most of the jobs and personnel of the former NUPEC (Nuclear Power Engineering Corporation) were transferred into JNES.


Two divisions are relating seismic engineering and technology: The Safety Analysis and Evaluation Division covers analysis and evaluation for seismic input and seismic design, probabilistic seismic hazard analysis, seismic PSA (probabilistic safety assessment), structure analysis, tsunami analysis and so on. The Safety Standard Division covers shaking table tests of components and piping, earthquake observation and evaluation, soil-structure interaction tests and evaluation and so on.

Activities in the Field of Seismic Safety Analysis

The Safety Analysis and Evaluation Division is responsible for technical support to the NISA at safety review, analysis and evaluation of accidents or troubles in nuclear facilities, improvement of safety regulation, etc. The technical field of the division covers reactor physics, thermal-hydraulics, seismic and structural analysis, nuclear safety analysis, probabilistic safety assessment, etc.

Main items in the field of seismic safety analysis are overviewed in the following.

(1) Evaluation of Seismic Ground Motion

Evaluation of seismic ground motion and review of the input ground motions for nuclear power plants (NPP) and other nuclear facilities have been done using the conventional analysis techniques and also state of the art techniques such as faulting models.

One of the recent important topics is the development of a new methodology to evaluate seismic ground motions caused by the rupture of unknown inland earthquake sources (buried and undefined active faults) near a site based on the probabilistic method. Basic idea of this methodology is shown in Figure 1.

The methodology consists of three steps: (a) evaluation of the earthquake occurrence frequency caused by unknown earthquake sources, which is evaluated by combining the Gutenberg-Richter relation (occurrence frequency vs. magnitude) and the ratio of earthquakes without surface fault (surface rupture) at each magnitude, (b) evaluation of response spectra of ground motions for scenario earthquakes caused by buried faults at each magnitude, and (c) evaluation of the uniform hazard response spectra vs. exceedance probability by summing up the frequencies obtained at step (a) of the response spectra obtained at step (b).
At step (a) the earthquakes occurrence frequency was obtained for each Japan Meteorological Agency (JMA) Magnitude Mj of 5 to 7.4 based on the JMA earthquake catalogue. The probability of earthquakes without surface fault was predicted from the relation between fault parameters (such as depth of asperity, stress drop) of faults and surface displacement caused by rupture of the faults. At step (b) variations of buried fault models of Mj of 5 to 7.4 around a site were taken into account with considering uncertainties in the source characteristics (distance, depth, stress drop, etc.) and the propagation characteristics (cut-off frequency, etc.) and ground motions of scenario earthquakes caused by the rupture of these modeled faults were evaluated by the hybrid wave synthesis technique and also by empirical attenuation correlations. At step (c) the relation of response spectra and exceedance probability was evaluated and compared with observed ground motions.

In connection with the evaluation mentioned above, distributions of the seismogenic layer depth of the observed earthquakes were analyzed and the upper and lower cutoff depths of earthquake source layer for each seismic zone in Japan were estimated. Physical prospecting data investigating selected important active faults in Japan were also analyzed to evaluate the practical capability of the existing physical measurement methods.

(2) Seismic Response Analysis

Evaluations of seismic response of buildings, structures and components have been carries out for the review of ruggedness and seismic safety of NPP and other nuclear facilities and also for seismic PSA of NPP. The finite element dynamic analysis method to evaluate stability of the slope and the discrete element method to evaluate collapse behavior of unstable soil or rocks and collision behavior of rocks to the structure have been developed.

The methodology of slope stability and collapse analysis and its example is shown in Figure 2.

(3) Seismic Probabilistic Safety Assessment (PSA)

Seismic PSA is one of the most important tasks in the field of seismic safety analysis of the Safety Analysis and Evaluation Division. The methodologies and database of seismic PSA have been developed intensively. The outline of the methodologies is shown in Figure 3. Seismic PSA of level 1 to level 3 has been performed for standard types of power plants; two types of BWR and two types of PWR.
Figure 2. An example of analysis of slope stability and collapse

![Diagram showing analysis process]

Figure 3. Procedure of seismic PSA

The features of the methodology are the followings: (a) Seismic hazard analysis: Expert opinions are elicited and used for seismic source characterization and selection of attenuation relation, and logic trees for earthquake occurrence frequency models and ground motion propagation models were formed and analyzed to obtain seismic hazard curves. Empirical attenuation relations and fault model analysis for near faults, if necessary; are used to the analysis; (b) Fragility analysis: Probabilistic seismic response is calculated by the inelastic response analysis method with the Latin Hypercube Sampling technique in order to consider uncertainties in soil and material properties and input ground motions. Failure probability of building and structures is calculated by comparing response strain distribution and the strain limit obtained by tests. Seismic capacity of components has been evaluated by using shaking test data and structural analysis. Database of seismic capacity of each category of components has been prepared for standard BWR and PWR; (c) Accident sequence analysis: The event tree and fault tree technique is used to analyze accident sequences. Several hundreds of sequences were quantified to obtain core damage frequency (CDF), importance of each component and sensitivity of
each uncertain parameter to CDF. Correlation of failure of components is taken into account in the system analysis. The correlation coefficients between responses of components have been calculated for various combination of place of settlement, natural frequency, damping factor of the components.

An example of evaluation of failure probability of structure is shown in Figure 4. In the evaluation of fragility curve of seawater pit, seismic capacity of the structure was calculated for the limit deformation angle of the structure. Median seismic response was calculated by the non-linear dynamic FEM analysis considering soil-structure interaction. Probability distribution of the response was calculated by a simplified analytical method using soil response analysis and shear strain transmitting relation between the soil and the structure.

Figure 4. An example of fragility evaluation of seawater pit

Fragility curve of seawater pit
Maximum acceleration on free bedrock (Gal)
Cumulative failure probability
0.0 0.2 0.4 0.6 0.8 1.0
0.00 500 1000 1500 2000
300Gal 600Gal
900Gal
Limit state of bulkhead
Limit state of side wall

Analysis model of seawater pit

Deformation angle=\theta

Seawater pit
Surface ground
Vs=1000m/s
Vs=1500m/s
Bed rock
30m
20m

Deformation of seawater pit and ground

Seawater pit
PGA=900Gal

Analysis of several examples of tsunamis occurred in the past has been performed with these data and compared with the observed wave heights and their arrival times. An example of analysis results for a tsunami caused by a presumed earthquake at the Pacific Ocean plate interface is shown in Figure 5.

Figure 5. An example of snapshot of tsunami analysis

(4) Tsunami Analysis

There is a high possibility of occurrence of tsunami at the Japanese island, if big earthquakes occur at the sea around this island. The geomorphic data of the seabed surrounding the Japanese island have been developed; standard mesh geomorphic data for wide area and detailed mesh data for narrow area near each site. Analysis of several examples of tsunamis occurred in the past has been performed with these data and compared with the observed wave heights and their arrival times. An example of analysis results for a tsunami caused by a presumed earthquake at the Pacific Ocean plate interface is shown in Figure 5.
Activities in the Field of Seismic Tests and Researches

The Structural Reliability Evaluation Group of the Safety Standard Division is making efforts on research works to improve seismic regulations through seismic tests or investigation. Those studies vary on extensive areas from methodologies to determine the design base earthquake ground motion to evaluation methodologies of the integrity and functionality of the components and structures. The aim of seismic tests is recently changing to focus on examination of structural or functional limit (fragility test) to improve the accuracy of the evaluation of margin or to help the probabilistic seismic safety assessment (seismic PSA). Therefore, projects of the Group are almost following such a tendency.

(1) Proving Tests on the Seismic Reliability for Nuclear Power Plant

The vibration tests shown below are currently carried out, using test models of actual or near actual size. Based on the test results, seismic reliability, safety margin for function and adequacy of seismic design methods are confirmed. And also, the technology to evaluate seismic reliability of components is being prepared, making a lot of efforts in establishing simulation analysis methods which can simulate the behavior of test models.

(a) Ultimate Strength of Piping System
   (1998 to 2003)

The safety margin of the seismic design method for piping system was clarified by implementing various tests and simulation analysis. And, the safety margin of the seismic allowable stress was also evaluated taking consideration of the elasto-plastic behavior. Figure 6 shows an example of ultimate strength tests.

(b) Equipment Fragility (2002 to 2005)

A series of functional tests of safety related equipments is under implementation to get fragility data for seismic PSA and deterministic margin evaluation (see Figure 7).

As for the horizontal shaft pump and electrical equipments, using an amplified shaking table, vibration tests under very high acceleration (maximum acceleration: 6G) were performed. The data of fragility is under evaluation.

As for the scrammability of control rods (for both BWR and PWR), the vibration tests up to 3G are currently under implementation.

As for the vertical shaft pump, the vibration test of actual size is scheduled in early 2005.

Figure 6. Ultimate strength test: Pressurized water gush out from the rupture

Figure 7. Fragility test: Electric panels on the sub-table to amplify excitation level to 6G
(c) Future Development: Seismic Integrity of Aged Equipment (2004 to 2006)

In order to respond for aged degradation occurring in the equipment, the vibration tests of the reactor internals (BWR core shroud: Figure 8) and PLR piping will be performed, assuming the defect due to stress corrosion cracking.

The seismic safety margin of the aged equipments by Japanese fitness-for-service rules will be confirmed, and the methodology to evaluate the structural integrity of the equipment with defects under large seismic input will be established.


To study the effect of three directional earthquake ground motion on the seismic capacity of buildings, "Multi-Directional Loading Test of Reactor Building" had been carried out from 1994 through 2003 to study various properties of seismic shear walls of reinforced concrete structures and to accumulate their test data. In 2003, the final year of the project, the dynamic loading test of a cylindrical wall specimen was performed using a three dimensional shaking table and their results were processed and analyzed. In addition, the test was summarized in overall and the restoring force characteristics (seismic capacity and deformation) of seismic shear walls under the simultaneous multi-directional loading conditions were evaluated. (Figure 9)


It is said that the characteristics of earthquake ground motion are being defined at the seismic bed-rock (the rock with the shear wave velocity more than 3000m/s) where we can exclude site specific amplification.

To evaluate seismic motion on the seismic bed-rock, two deep downhole seismographic arrays at Kobe and Narita were assembled between the ground surface and the seismic bedrock for continuous earthquakes observation. (Figure 10)
Using the observed records, the analytical method and model which can accurately simulate wave propagation is being developed. Then seismic waves at the seismic bedrocks, where only seismic records at the ground surfaces are gotten, can be estimated with this method. Collecting many of these waves, the average image of earthquake ground motion at the seismic bed-rock will be clarified and the recommended evaluation method of the reference earthquake ground motion for design will be established by the end of 2004 fiscal year.


To obtain soil-structures interaction data under extreme acceleration level, and to improve evaluation method, it is planned to subject a model of nuclear reactor building installed on the real field to some big artificial earthquake ground motions with paying attention to the non-linear behaviors of the model such as foundation uplift etc. (Figure 11).

It is planned to use a controlled blasting for coalmining in this test, which ignites vast amount of explosive with time delay and can generate the vibration similar to the real earthquake ground motion.

In 2004 and 2005, test method will be investigated in detail as phase-I study such as what kind input wave and what level of response we can have, and how to measure uplift of the mat etc. Thereafter, “Phase-II, Test and Evaluation” is planned for four years of 2006 to 2009.